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STATIC STABILITY CHARACTERISTICS
OF THE ALARR PAYLOAD AND THE EFFECT OF
THE WAKE ON THE BALLUTE DECELERATOR
CHARACTERISTICS AT TRANSONIC SPEEDS

Warren E. White and Travis R. Brice

ARO, Inc.

December 1965

PROPULSION WIND TUNNEL FACILITY
ARNOLD ENGINEERING DEVELOPMENT CENTER
AIR FORCE SYSTEMS COMMAND
ARNOLD AIR FORCE STATION, TENNESSEE

NOTICES

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FOREWORD

The work reported herein was done at the request of the Air Force Special Weapons Center (AFSWC), Air Force Systems Command (AFSC), Kirtland Air Force Base, New Mexico, under System 921A.

The results of the test presented were obtained by ARO, Inc. (a subsidiary of Sverdrup and Parcel, Inc.), contract operator of the Arnold Engineering Development Center (AEDC), AFSC, Arnold Air Force Station, Tennessee, under Contract AF40(600)-1200. The test was conducted from September 20 through October 4, 1965, under ARO Project No. PA0612, and the manuscript was submitted for publication on November 19, 1965.

This technical report has been reviewed and is approved.

Francis M. Williams   Jean A. Jack
Major, USAF   Colonel, USAF
AF Representative, PWT   DCS/Test
DCS/Test

ABSTRACT

Drag data were obtained at Mach numbers 0.5, 0.8, and 1.2 for the Goodyear Aerospace Corporation ballute decelerator in the wake of the payload of the Air Launch Air Recovery Rocket (ALARR). Two model sizes of the ALARR payload were tested at angles of attack of 0 and 20 deg placed at 2, 3, 4, 5, and 6 payload diameters forward of the decelerator. The decelerator remained at zero angle of attack. The wake influence of the larger payload reduced the drag of the decelerator, both at 0- and 20-deg angles of attack. In addition, static stability characteristics were obtained on the ALARR payload for a Mach number range from 0.5 to 1.5 and an angle-of-attack range from -4 to +22 deg. To maintain static stability the center of gravity cannot move more than 29 percent of the model length aft of the nose.

CONTENTS

ILLUSTRATIONS

NOMENCLATURE

A_B	Decelerator cross-sectional area based on maximum decelerator diameter without fence, 0.01502 sq ft
A_b	Stability payload model base area, 0.01173 sq ft
C_A	Axial-force coefficient, axial force/$q_\infty S$
$C_{A,b}$	Base axial-force coefficient, $\dfrac{p_\infty - p_b}{q_\infty} \cdot \dfrac{A_b}{S}$
$C_{A,F}$	Forebody axial-force coefficient, $C_A - C_{A,b}$
C_D	Decelerator drag coefficient, drag/$q_\infty A_B$

C_m Pitching-moment coefficient referenced to the model nose, measured pitching moment/$q_\infty S D_S$

C_N Normal-force coefficient, normal force/$q_\infty S$

C_{N_α} Rate of change of normal-force coefficient with angle of attack $(dC_N/d\alpha)_{\alpha=0}$, per deg

D Payload diameters, 0.07933 ft and 0.1088 ft

D_S Stability model reference diameter, 0.125 ft

L Model length (see Fig. 4), in.

M_∞ Free-stream Mach number

p_b Stability model base pressure, psf

p_∞ Free-stream static pressure, psf

q_∞ Free-stream dynamic pressure, 0.7 $p_\infty M_\infty^2$, psf

R Radial coordinate of model (see Fig. 4), in.

Re/ft Reynolds number per foot

S Stability model reference area, 0.01227 sq ft

X Longitudinal coordinate of model (see Fig. 4), in.

x Payload and decelerator separation distance, in.

x_{cp} Center-of-pressure location in model reference diameters, negative aft of model nose (C_m/C_N)

x_{np} Neutral-point location in model reference diameters, negative aft of model nose $(dC_m/dC_N)_{\alpha=0}$

α Payload model angle of attack, positive nose up, deg

SECTION I
INTRODUCTION

The Air Launch Air Recoverable Rocket (ALARR) is an air sampling rocket designed to take atmospheric samples at altitudes above 60,000 ft. To recover the payload, Goodyear Aerospace Corporation is developing a ballute decelerator to decelerate the payload to a desired velocity before deploying the recovery parachute. A test program was initiated to simulate a 22-in.-diam and a 30-in.-diam ballute decelerator in the wake of the ALARR payload. This was accomplished by placing payload models of two sizes forward of the ballute decelerator model. Drag data for the decelerator at Mach numbers 0.5, 0.8, and 1.2 were obtained by placing the payloads at 2, 3, 4, 5, and 6 payload diameters forward of the ballute. The payloads were set at angles of attack of 0 and 20 deg. The decelerator remained at zero angle of attack.

In addition, static stability of the ALARR payload was obtained at a Mach number range from 0.5 through 1.5 for an angle-of-attack range from -4 to +22 deg.

SECTION II
APPARATUS

2.1 WIND TUNNEL

The Aerodynamic Wind Tunnel, Transonic (1T) is an open-circuit, continuous flow wind tunnel capable of operating at Mach numbers from 0.50 to 1.50. The total pressure is approximately 1.4 atm throughout the operating range. The test section is 12 in. square, 37.5 in. long, and has perforated walls as shown in Fig. 1. A more detailed description of the tunnel may be found in the Test Facilities Handbook.[1] Photographs showing typical model installations are presented in Figs. 2 and 3. The sidewalls with 8- by 12-in. glass inserts were used only for the schlieren photography phase of the test.

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[1]Test Facilities Handbook (5th Edition). "Propulsion Wind Tunnel Facility, Vol. 3." Arnold Engineering Development Center, July 1963.

2.2 TEST ARTICLES

The dimensions of the models are presented in Fig. 4. A 0.075-scale payload was tested with a 0.075-scale model of a 22-in.-diam decelerator, and the same decelerator model was tested with a 0.055-scale payload, in which case the decelerator model represented a 30-in.-diam decelerator at 0.055-scale. The payloads were mounted on a strut at 0- and 20-deg angles of attack and were placed 2, 3, 4, 5, and 6 payload diameters forward of the decelerator. The decelerator was sting mounted and remained at zero angle of attack. No simulation was made of the riser line connecting the decelerator to the payload. The decelerator model was also tested alone. In addition, a 0.086-scale payload stability model was tested. This model was sting mounted.

The decelerator was mounted on an internal strain-gage load cell which measured drag force. The static stability model was mounted on an internal strain-gage balance which measured normal force, pitching moment, and axial force. Base pressures were measured on the stability model only and were obtained from two static pressure orifices located at the base of the model.

SECTION III
TEST DESCRIPTION

3.1 TEST PROCEDURE

The decelerator was tested alone and in the wake of the payloads at Mach numbers 0.50, 0.80, and 1.2. The decelerator was translated vertically to determine strut influences and the vertical position which would give minimum drag. The centerline of the test section was used as reference zero, and translation above the centerline was termed positive. The decelerator was translated ±2.5 in. The static stability model was tested at Mach numbers from 0.5 to 1.5 and at angles of attack from -4 to +22 deg. The tunnel was operated at stagnation pressures which ranged from approximately 2765 to 2897 psf, and stagnation temperatures which varied from 142 to 208°F. The temperature variation was used to alleviate moisture condensation. The slight variation in tunnel conditions caused a change in Reynolds number which is presented in Fig. 5 as a function of Mach number.

3.2 PRECISION OF MEASUREMENTS

The estimated uncertainties in the data are given in the following table and are based on a 95-percent probability.

UNCERTAINTIES

Symbol	$M_\infty = 0.5$	$M_\infty = 0.8$	$M_\infty = 1.2$	$M_\infty = 1.5$
M_∞	±0.003	±0.003	±0.015	±0.015
α, deg	±0.10	±0.10	±0.10	±0.10
q_∞, psf	±3	±3	±3	±3
C_D	±0.010	±0.006	±0.005	-
C_N	±0.017	±0.008	±0.006	±0.005
C_m	±0.036	±0.018	±0.013	±0.012
$C_{A,b}$	±0.016	±0.008	±0.006	±0.005
$C_{A,F}$	±0.015	±0.015	±0.011	±0.010

Angle of attack was corrected for sting and balance deflections. No corrections have been made for the test section flow inclination or tunnel wall interference. The uncertainty in Mach number given above is the deviation from the mean value in the test region. The uncertainty in setting and maintaining Mach number is estimated to be less than ±0.004.

SECTION IV
RESULTS AND DISCUSSION

4.1 DECELERATOR DRAG

The effects of the wake of the ALARR payload on the ballute decelerator are presented in Figs. 6 and 7 in terms of the variation of the drag coefficient with free-stream Mach number and separation distance, respectively. The decelerator was translated vertically to determine strut influences and the vertical position which would give minimum drag. Generally, the center of the payload wake, as determined from schlieren photographs, correlated with the position of minimum drag. The drag data presented are for the center-of-wake positions. For the payloads at $\alpha = 0$ deg, the wake center corresponded to the tunnel centerline. The strut influences on the position of the wake center and on the decelerator drag were considered to

3

be small. The curves for the decelerator alone are included in Figs. 6 and 7 to allow a comparison with payload and decelerator configurations. The wake influences of the larger payloads produced a generally lower drag on the decelerator at corresponding payload angles of attack of both 0 and 20 deg. The drag of the decelerator in the wake of either payload at α = 20 deg was less than that for either payload at α = 0 deg except at low values of x/D at M_∞ = 1.2. For all payload and decelerator configurations at Mach numbers 0.5 and 0.8, the drag remained essentially the same when the separation distance was increased from 2 to 6 payload diameters. For Mach number 1.2, the drag increased as separation distance increased except at large separation distances for the 0.075-scale payload at α = 0 deg. For the 0.055-scale payload (α = 0 deg) at all separation distances and the 0.075-scale payload (α = 0 deg) at small separation distances, the decelerator drag coefficient was equal to or greater than the decelerator-alone value for subsonic Mach numbers. This is not thoroughly understood; however, some difference is noted in the flow pattern over the decelerator. In particular, the flow appears to be separated ahead of the burble fence in the decelerator-alone case, but not in the decelerator-payload case. This suggests that the drag on the burble fence may be higher in the wake of the payload for the cited conditions. Different types of flow pattern can be seen in Fig. 8.

4.2 PAYLOAD STATIC STABILITY

Presented in Fig. 9 are the curves of C_N, C_m, x_{cp}, $C_{A,F}$, and $C_{A,b}$ obtained with the ALARR payload static stability model. The normal-force coefficient and pitching-moment coefficient exhibited a nonlinear variation for the angle-of-attack range tested; however, the curves exhibited an almost linear variation within the limits from -4 to +8 deg angle of attack. The pitching moment was referenced to the nose cf the model. On the x_{cp} plots, the neutral-point locations are also presented since x_{cp} is indeterminate near zero angle of attack.

The normal-force curve slope, C_{N_α}, and the neutral-point location, x_{np}, are presented in Fig. 10, and the $C_{A,F}$ and $C_{A,b}$ curves are presented in Fig. 11 as a function of Mach number for α = 0 deg. In the absence of the decelerator, the payload stability cannot be maintained if the center of gravity is more than 29 percent of the model length aft of the nose.
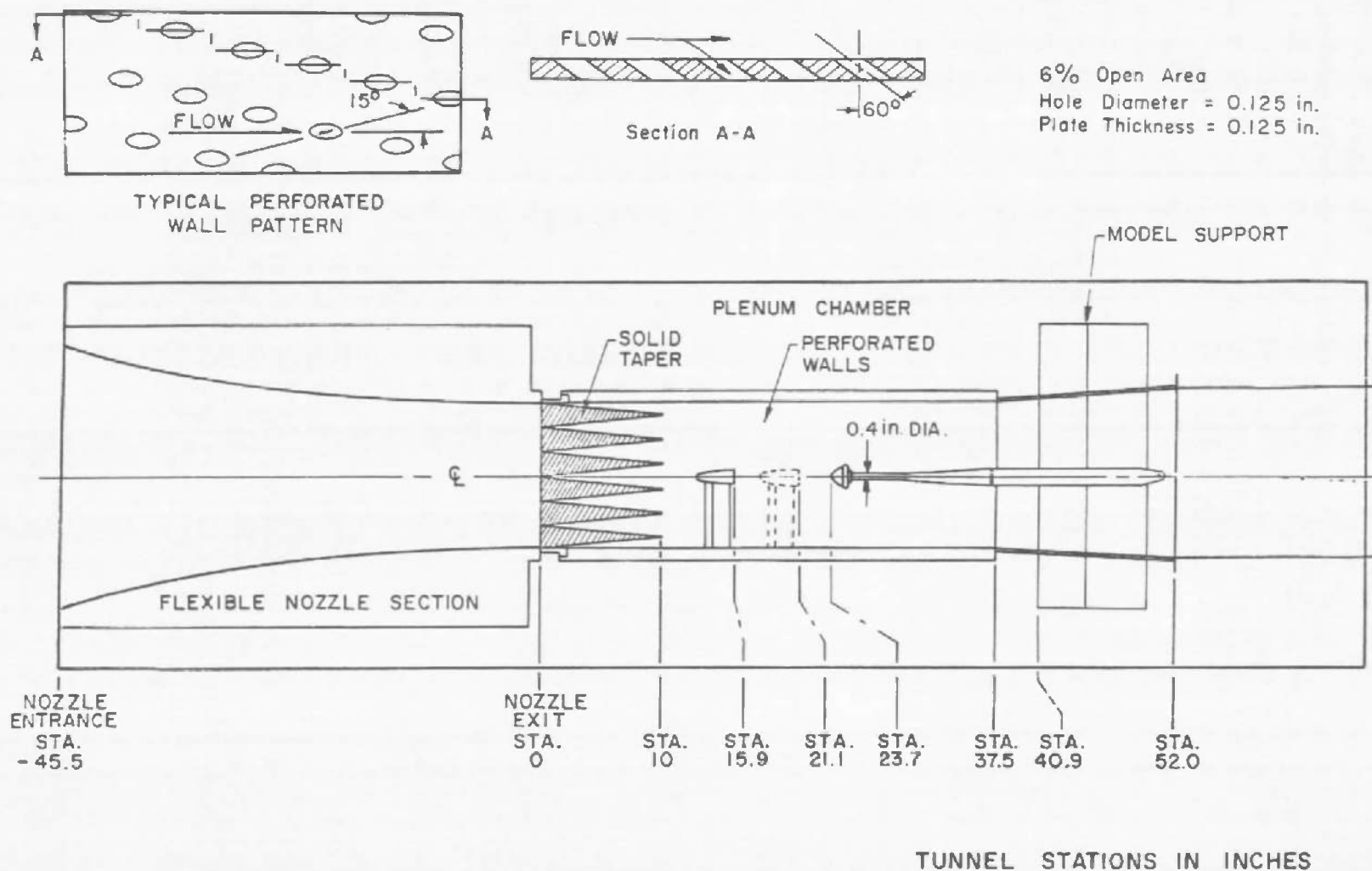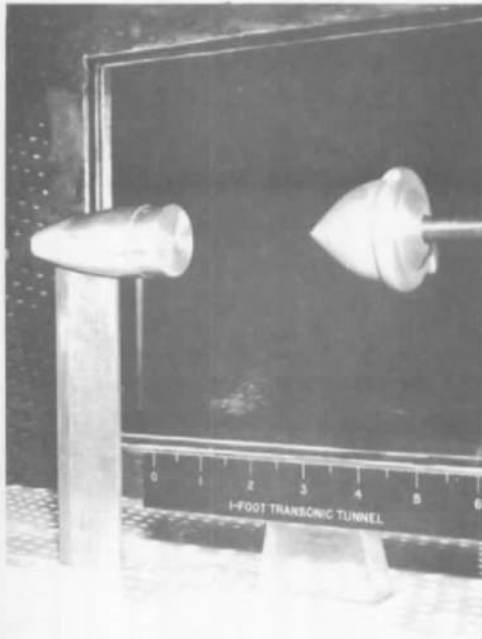
TYPICAL PERFORATED
WALL PATTERN

FLOW

15°

A

A

FLOW

Section A-A

60°

6% Open Area
Hole Diameter = 0.125 in.
Plate Thickness = 0.125 in.

MODEL SUPPORT

PLENUM CHAMBER

SOLID
TAPER

PERFORATED
WALLS

0.4 in. DIA.

C̱L

FLEXIBLE NOZZLE SECTION

NOZZLE
ENTRANCE
STA.
-45.5

NOZZLE
EXIT
STA.
0

STA.
10

STA.
15.9

STA.
21.1

STA.
23.7

STA.
37.5

STA.
40.9

STA.
52.0

TUNNEL STATIONS IN INCHES

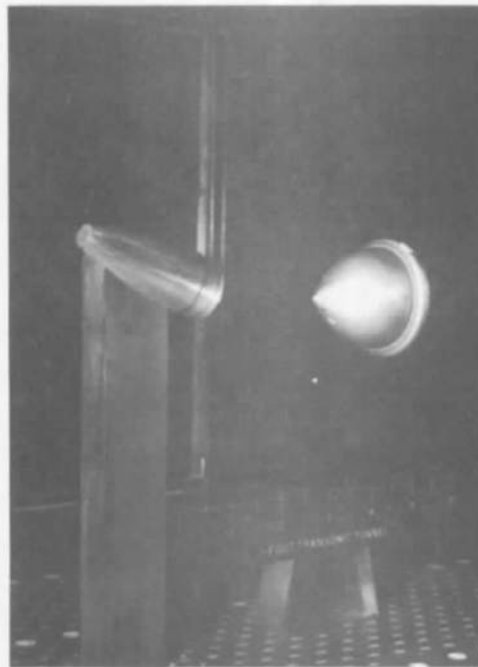Fig. 1 Schematic of Tunnel 1T with a Typical Decelerator-Payload Installation

0.075-Scale Payload,
x/D = 2, a = 0 deg
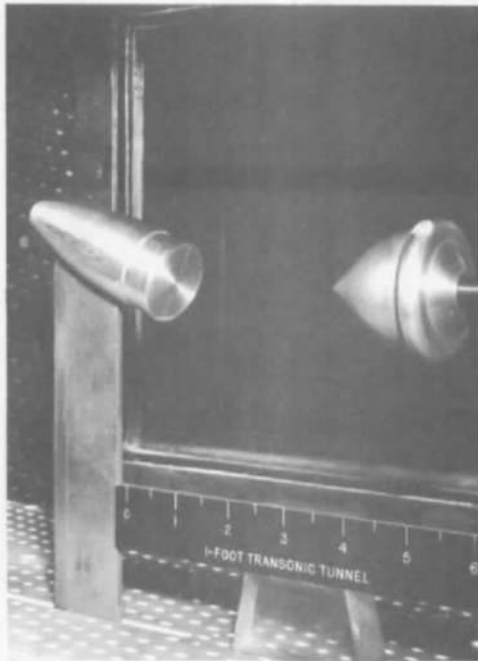
0.075-Scale Payload,
x/D = 2, a = 20 deg
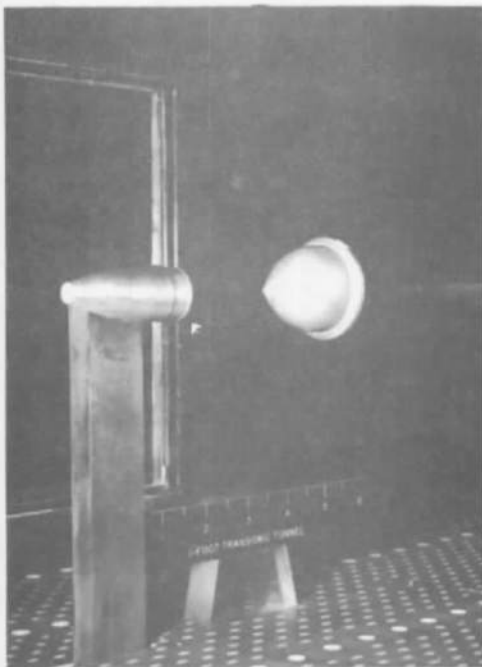
0.055-Scale Payload,
x/D = 2, a = 0 deg

0.055-Scale Payload,
x/D = 2, a = 20 deg

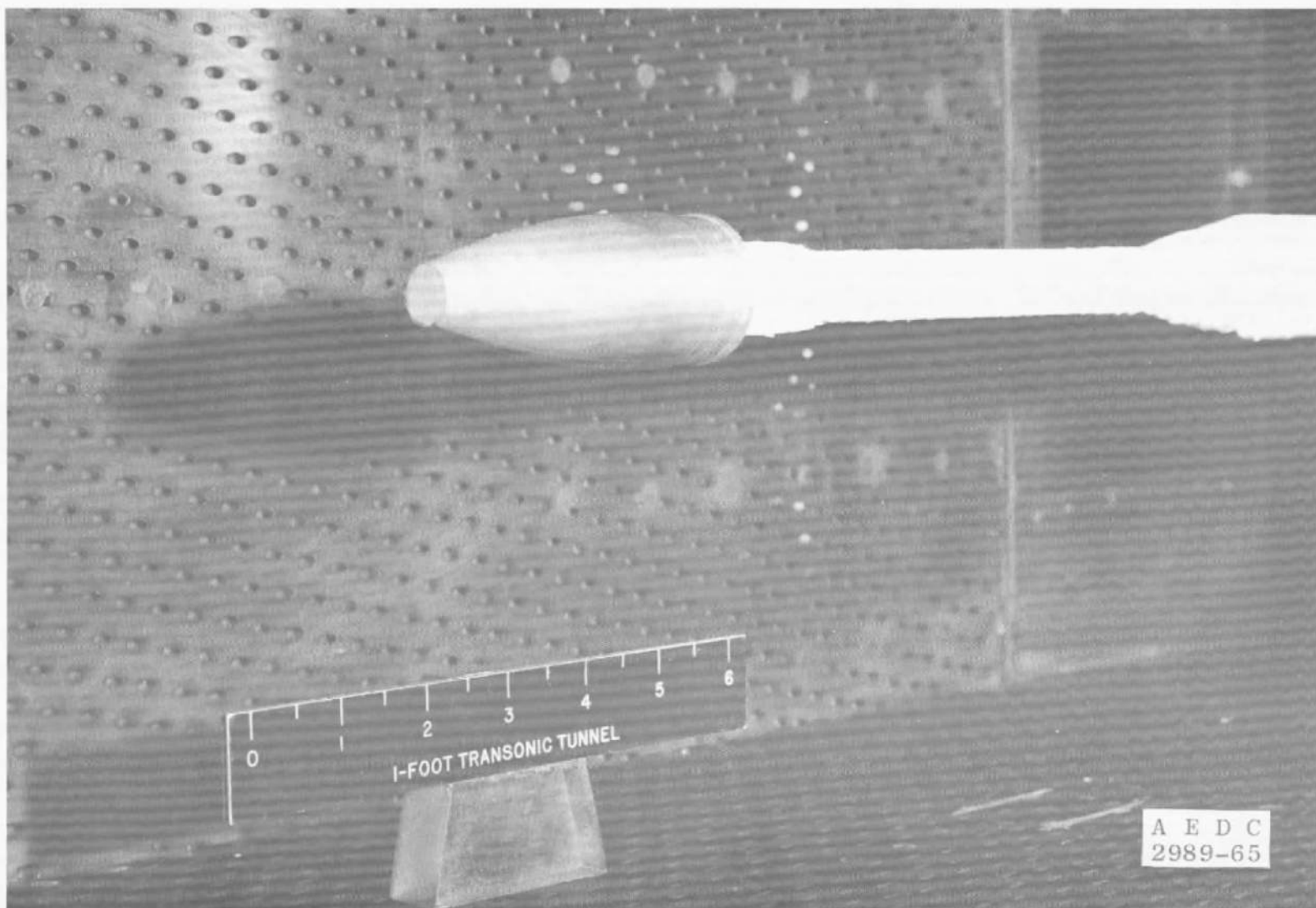Fig. 2 Decelerator-Payload Configurations Installed in the Test Section

Fig. 3 Static Stability Model Installed in the Test Section

PAYLOAD COORDINATES FOR THREE PAYLOADS			
PERCENT OF MODEL LENGTH	0.055-SCALE L = 2.230 in.	0.075-SCALE L = 3.041 in.	STABILITY L = 3.496 in.
X/L	R	R	R
0	0.174	0.240	0.275
6	0.219	0.299	0.344
19	0.302	0.411	0.473
31	0.367	0.501	0.576
43	0.414	0.565	0.649
56	0.451	0.616	0.708
64	0.467	0.636	0.731
68	0.471	0.642	0.738
72	0.474	0.646	0.743
77	0.477	0.650	0.747
86	0.478	0.652	0.750
90	0.451	0.615	0.707
100	0.467	0.638	0.733

DECELERATOR COORDINATES	
PERCENT OF MODEL LENGTH	0.075-SCALE L = 2.03 in.
X/L	R
0	0
13	0.23
26	0.46
39	0.65
52	0.77
65	0.82
73	0.83
78	0.98
85	0.98
90	0.68
91	0.64
98	0.42
100	0

ALL DIMENSIONS IN INCHES
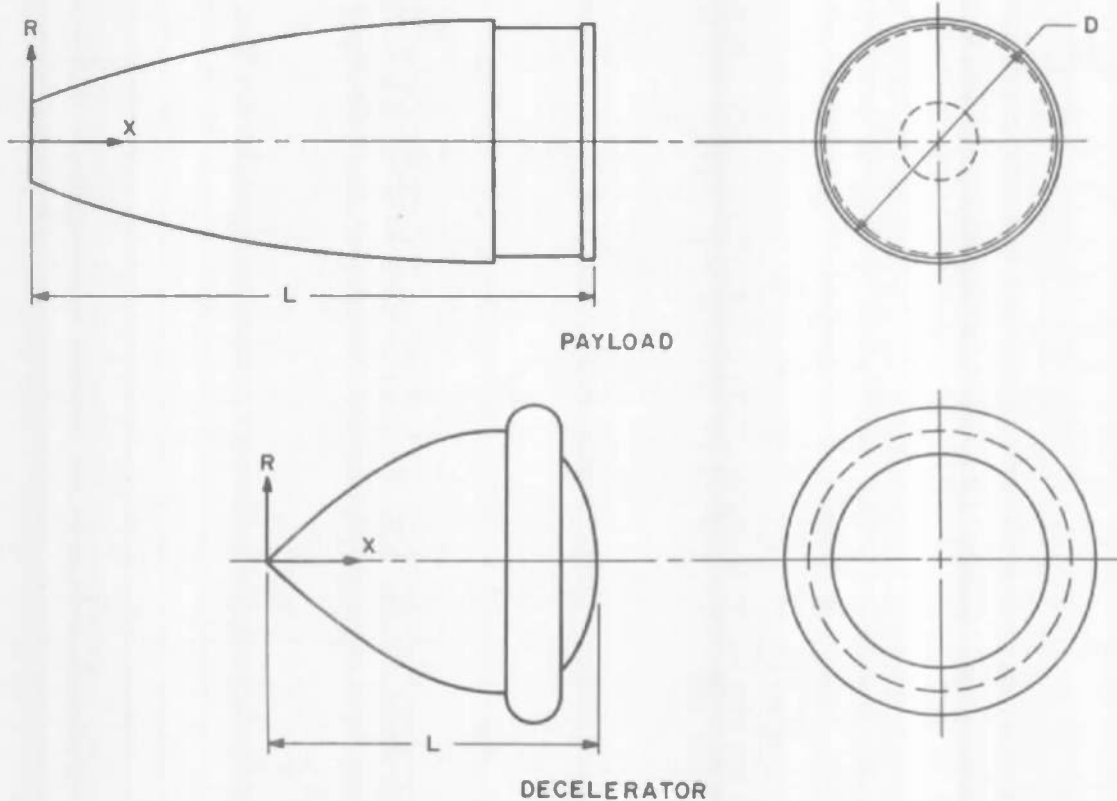SCALED DIMENSIONS ARE BASED ON
THE 22-in. FULL-SCALE BALLUTE

PAYLOAD
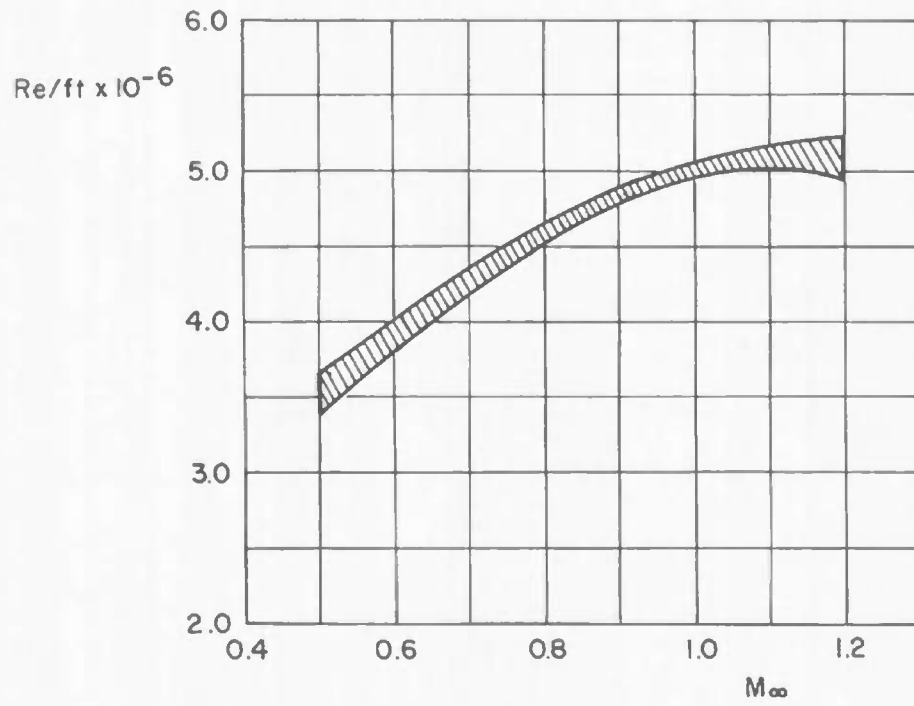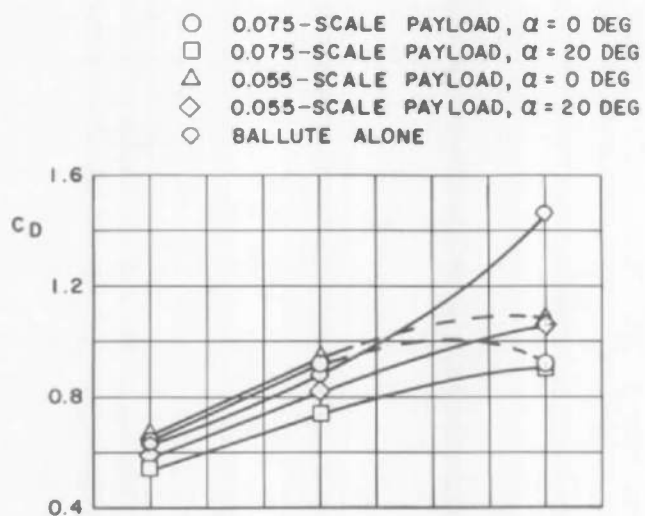
DECELERATOR

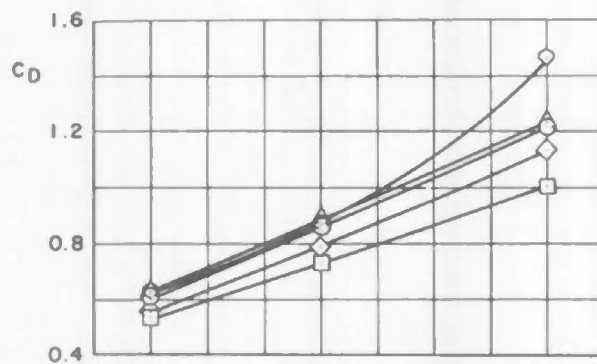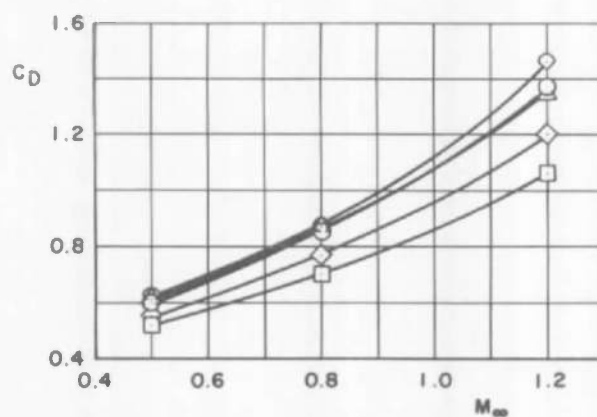Fig. 4 Details and Dimensions of Models

Fig. 5 Test Reynolds Number per Foot as a Function of Mach Number

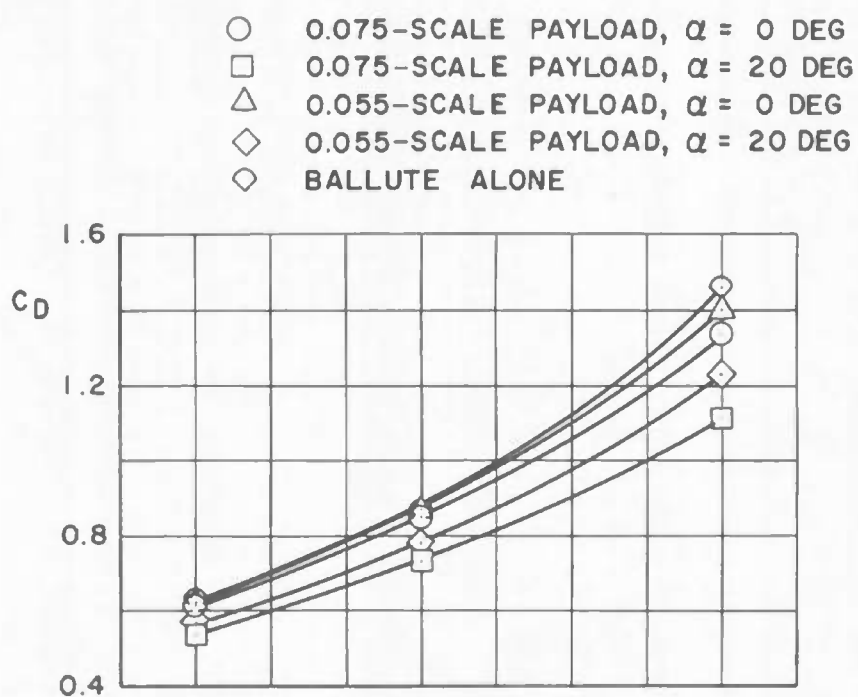a. Separation Distance of Two Payload Diameters

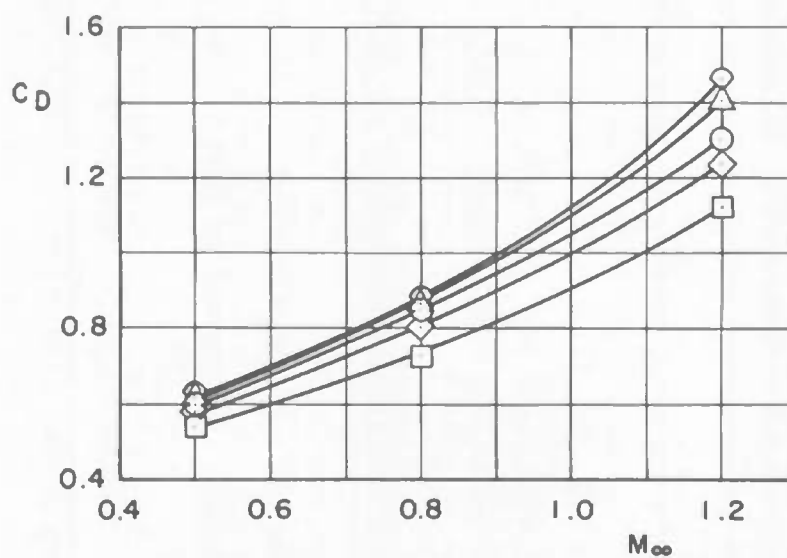b. Separation Distance of Three Payload Diameters

c. Separation Distance of Four Payload Diameters

Fig. 6 Effect of Mach Number Variation on the Decelerator Drag
Coefficient for Decelerator-Payload Separation Distances

○   0.075-SCALE PAYLOAD, α = 0 DEG
□   0.075-SCALE PAYLOAD, α = 20 DEG
△   0.055-SCALE PAYLOAD, α = 0 DEG
◇   0.055-SCALE PAYLOAD, α = 20 DEG
◇   BALLUTE ALONE

d. Separation Distance of Five Payload Diameters

e. Separation Distance of Six Payload Diameters

Fig. 6 Concluded

a. $M_\infty = 0.50$
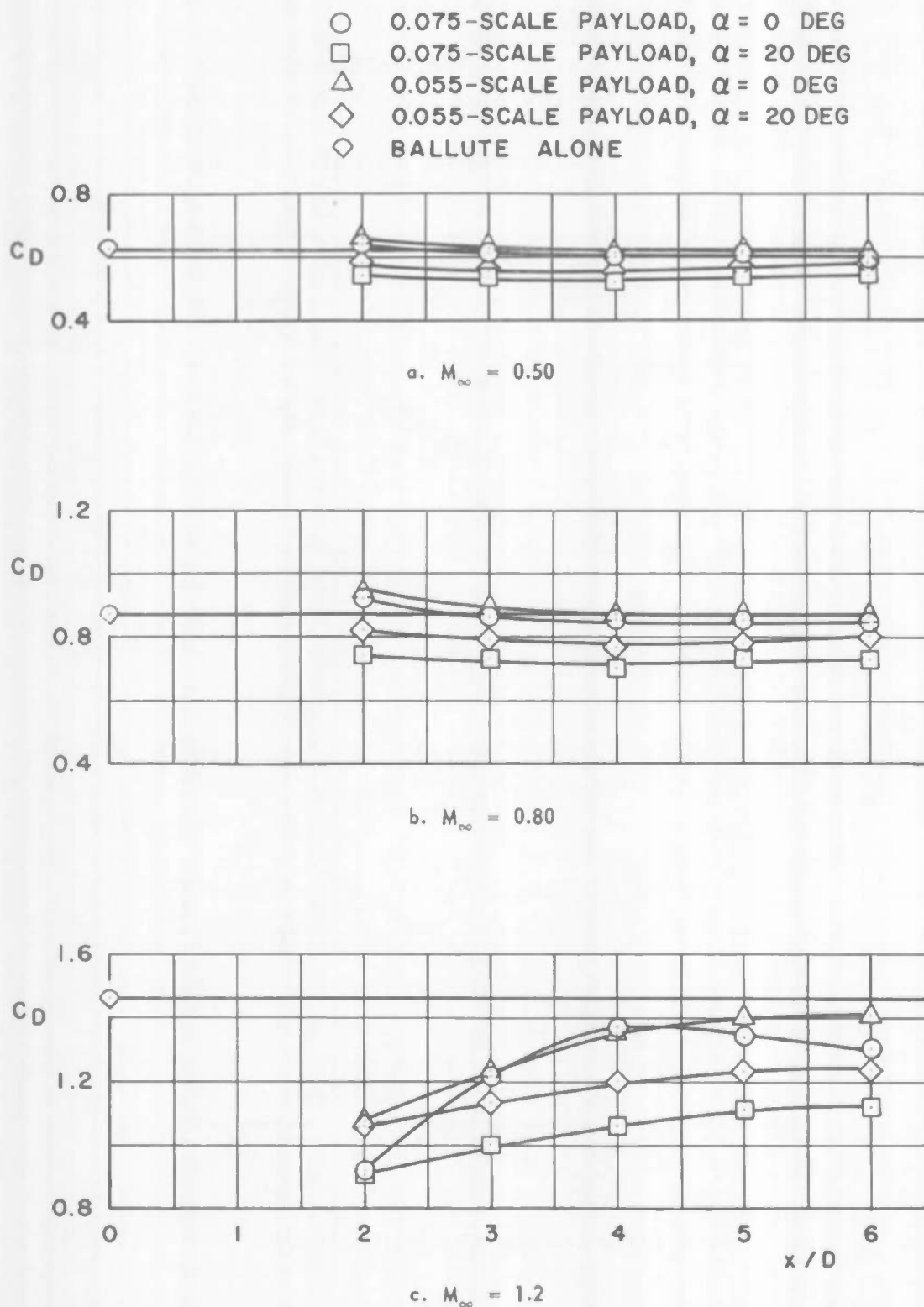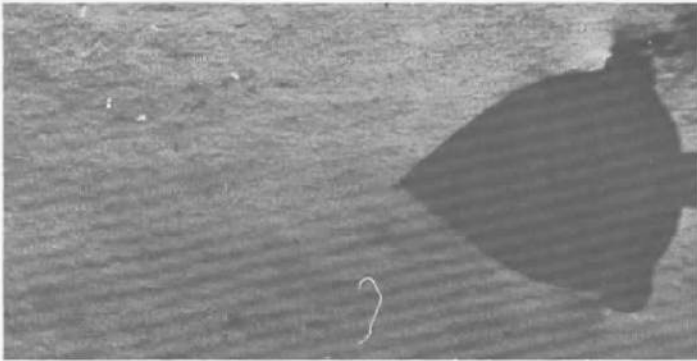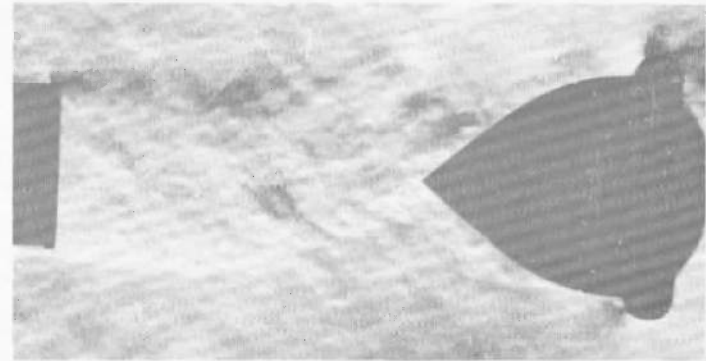
b. $M_\infty = 0.80$

c. $M_\infty = 1.2$

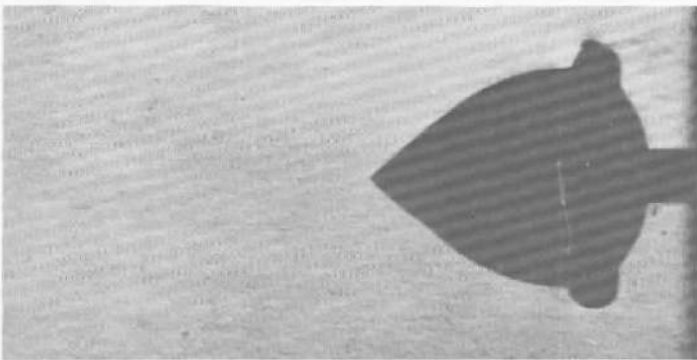Fig. 7 Effect of Decelerator-Payload Separation Distances on the Decelerator Drag Coefficient
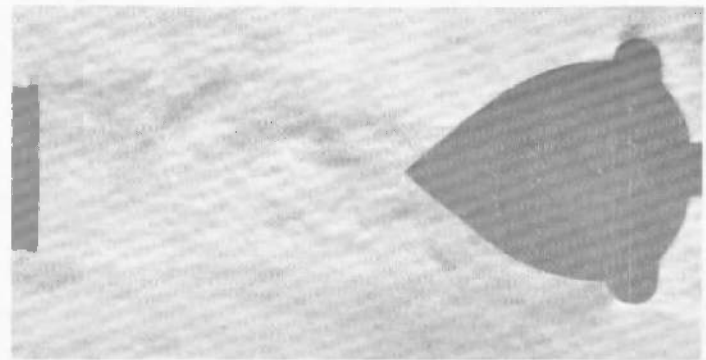
Decelerator Alone $M_\infty = 0.8$ Payload x/D = 2, α = 0 deg

Decelerator Alone $M_\infty = 0.5$ Payload x/D = 2, α = 0 deg

Fig. 8 Schlieren Photographs of Decelerator
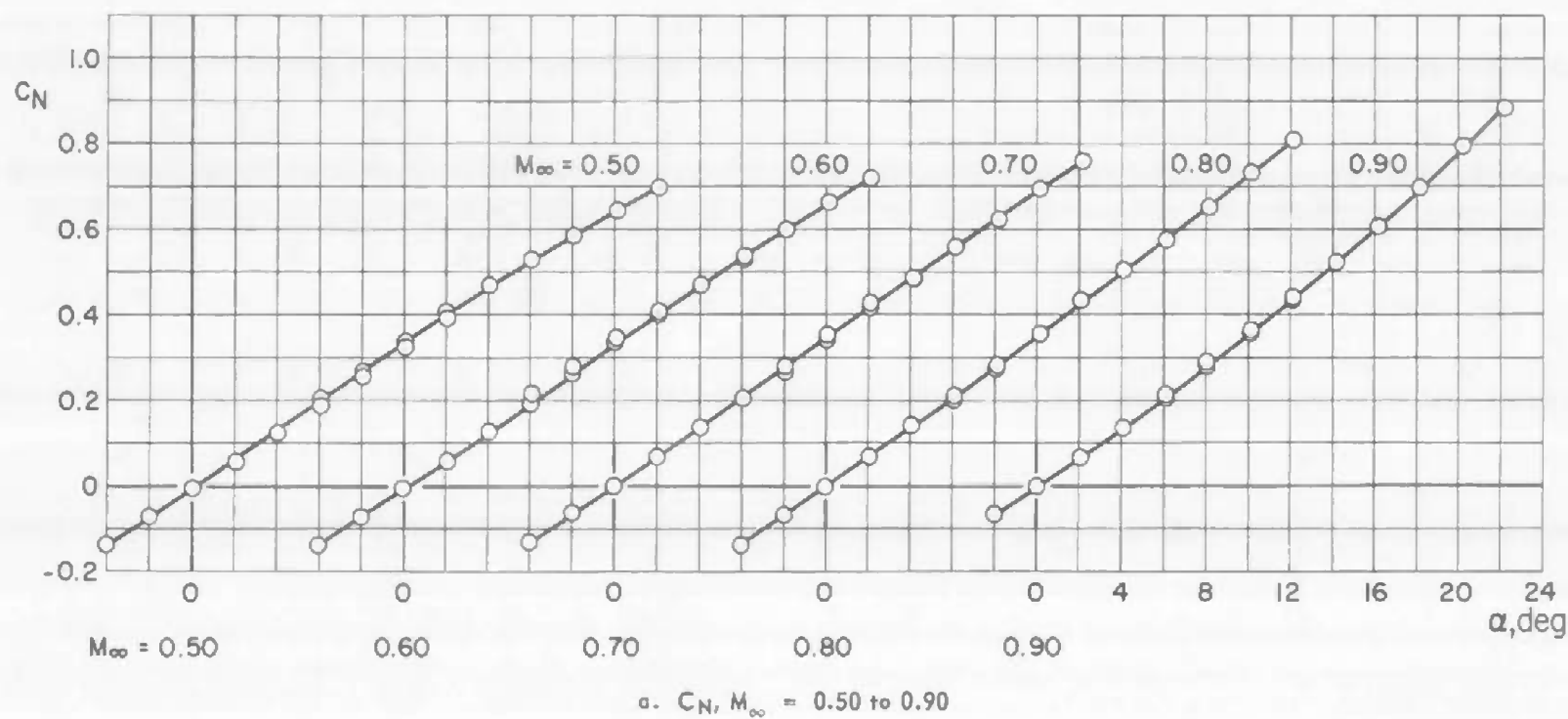
a. C_N, M_∞ = 0.50 to 0.90

Fig. 9 Effect of Angle of Attack on the C_N, C_m, x_{cp}, $C_{A,F}$, and $C_{A,b}$ Characteristics of the Static Stability Model
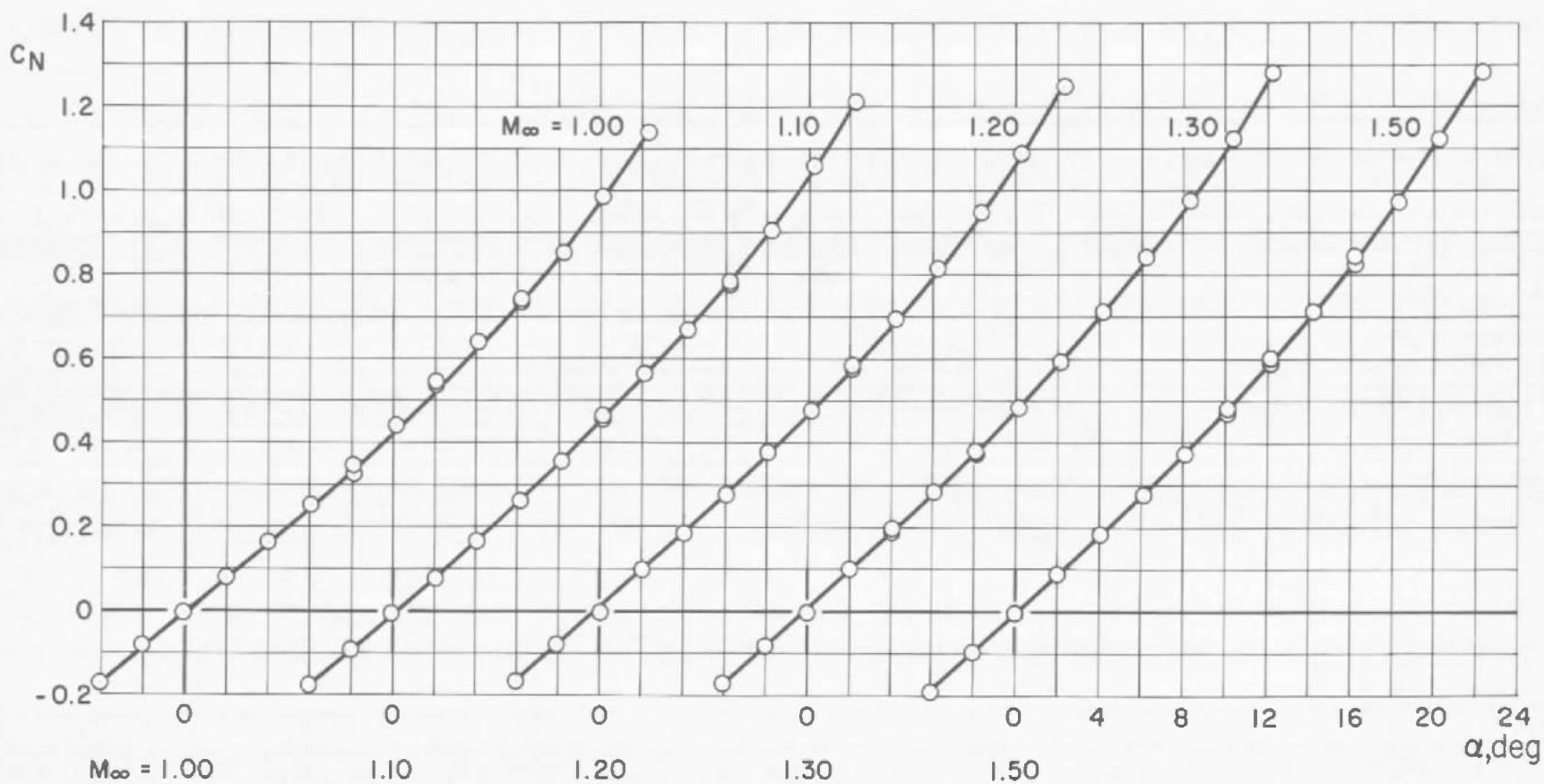
b. C_N, M_∞ = 1.00 to 1.50

Fig. 9 Continued
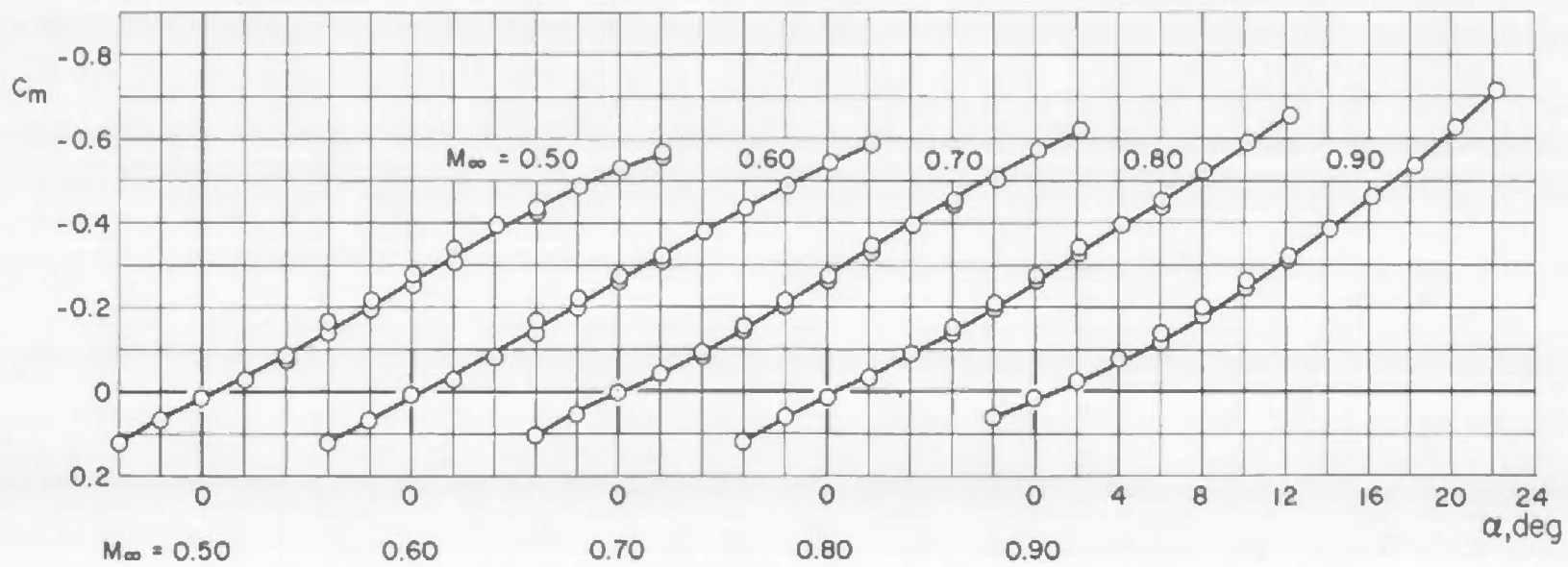
c. C_m, M_∞ = 0.50 to 0.90

Fig. 9 Continued

d. C_m, M_∞ = 1.00 to 1.50

Fig. 9 Continued

e. x_{cp}, M_∞ = 0.50 to 0.90

Fig. 9 Continued

FLAGGED SYMBOLS INDICATE NEUTRAL-POINT LOCATIONS
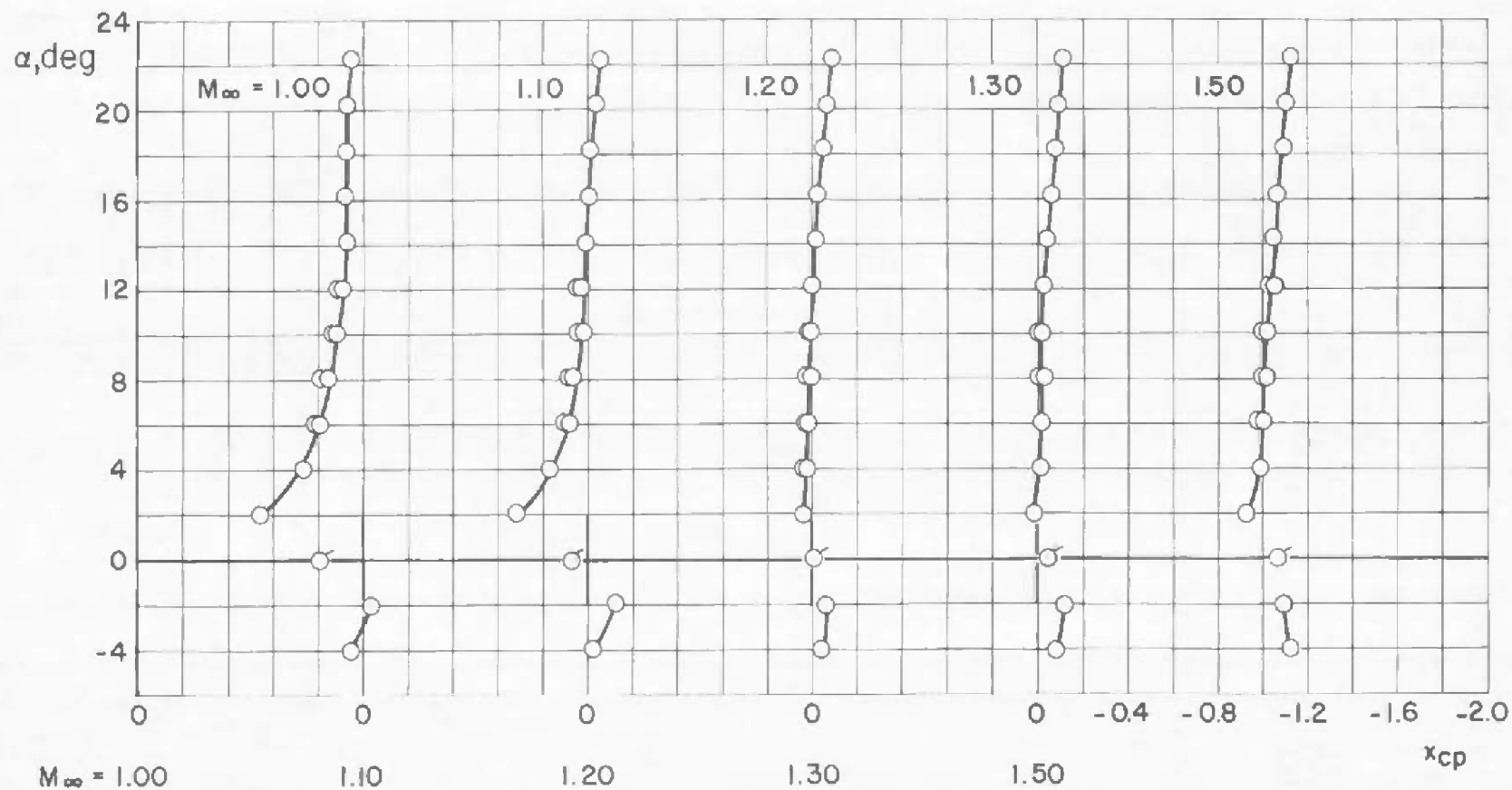
f. x_{cp}, $M_\infty = 1.00$ to 1.50

Fig. 9 Continued
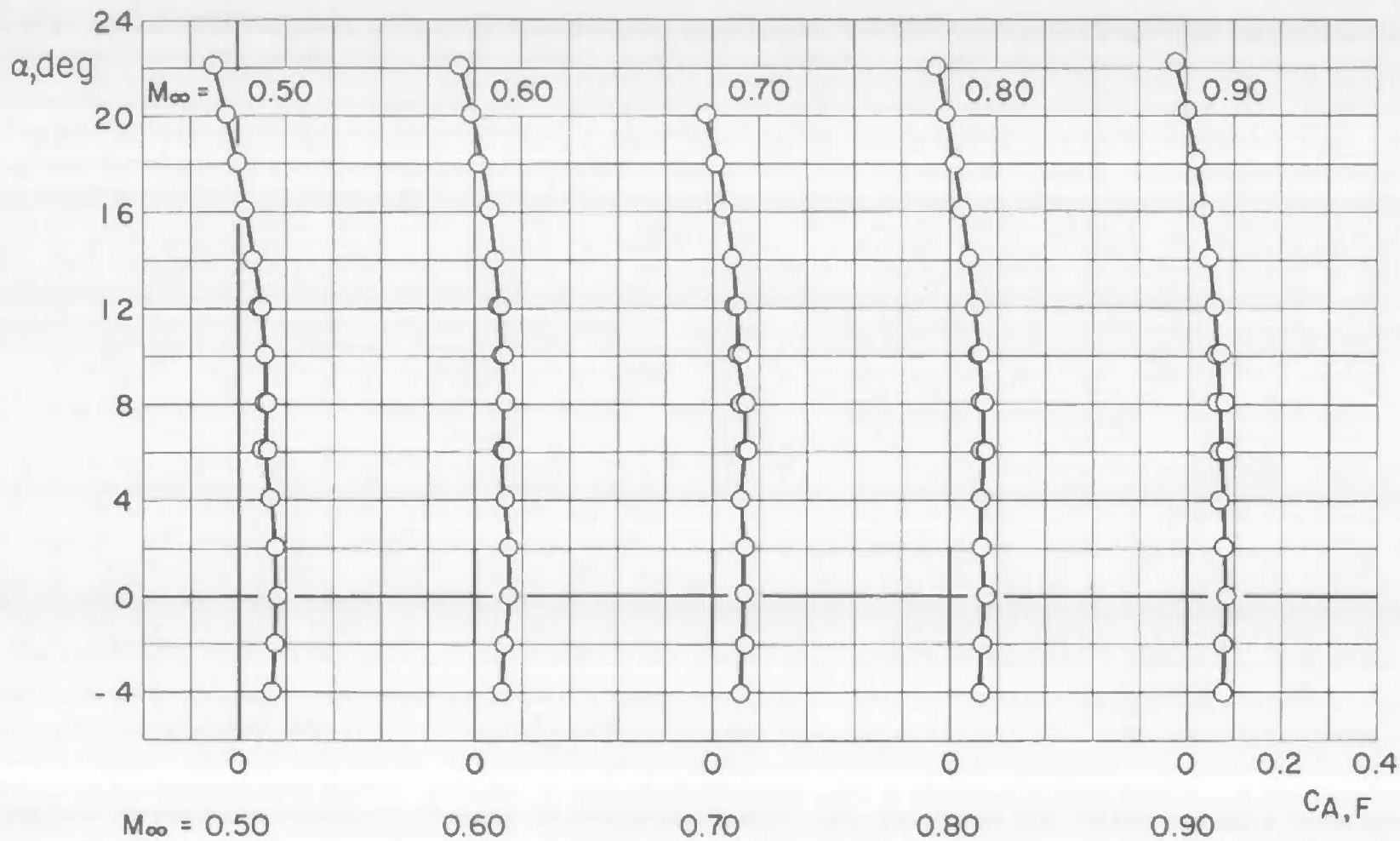
g. $C_{A,F}$, M_∞ = 0.50 to 0.90

Fig. 9 Continued
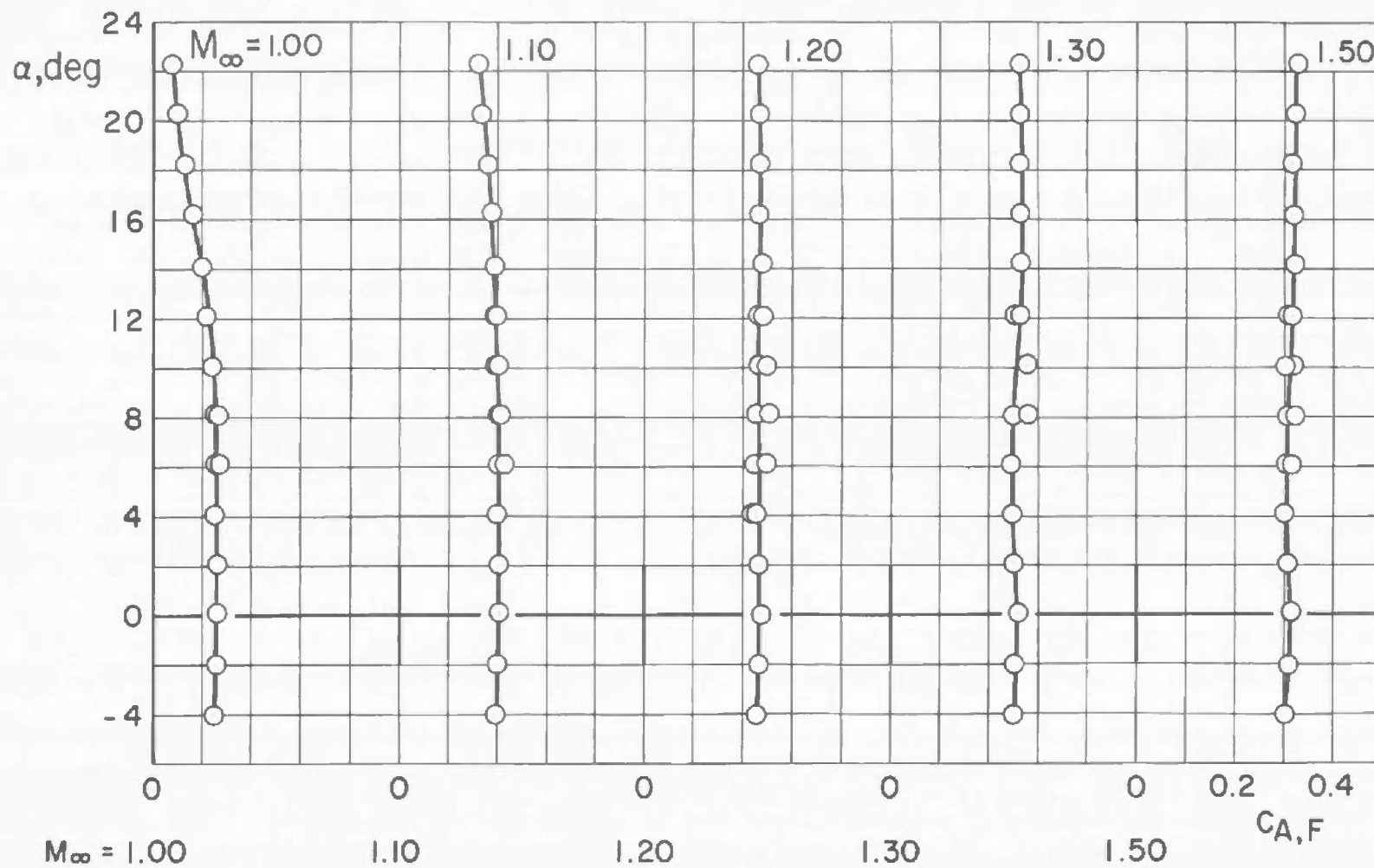
h. $C_{A,F}$, M_∞ = 1.00 to 1.50

Fig. 9 Continued
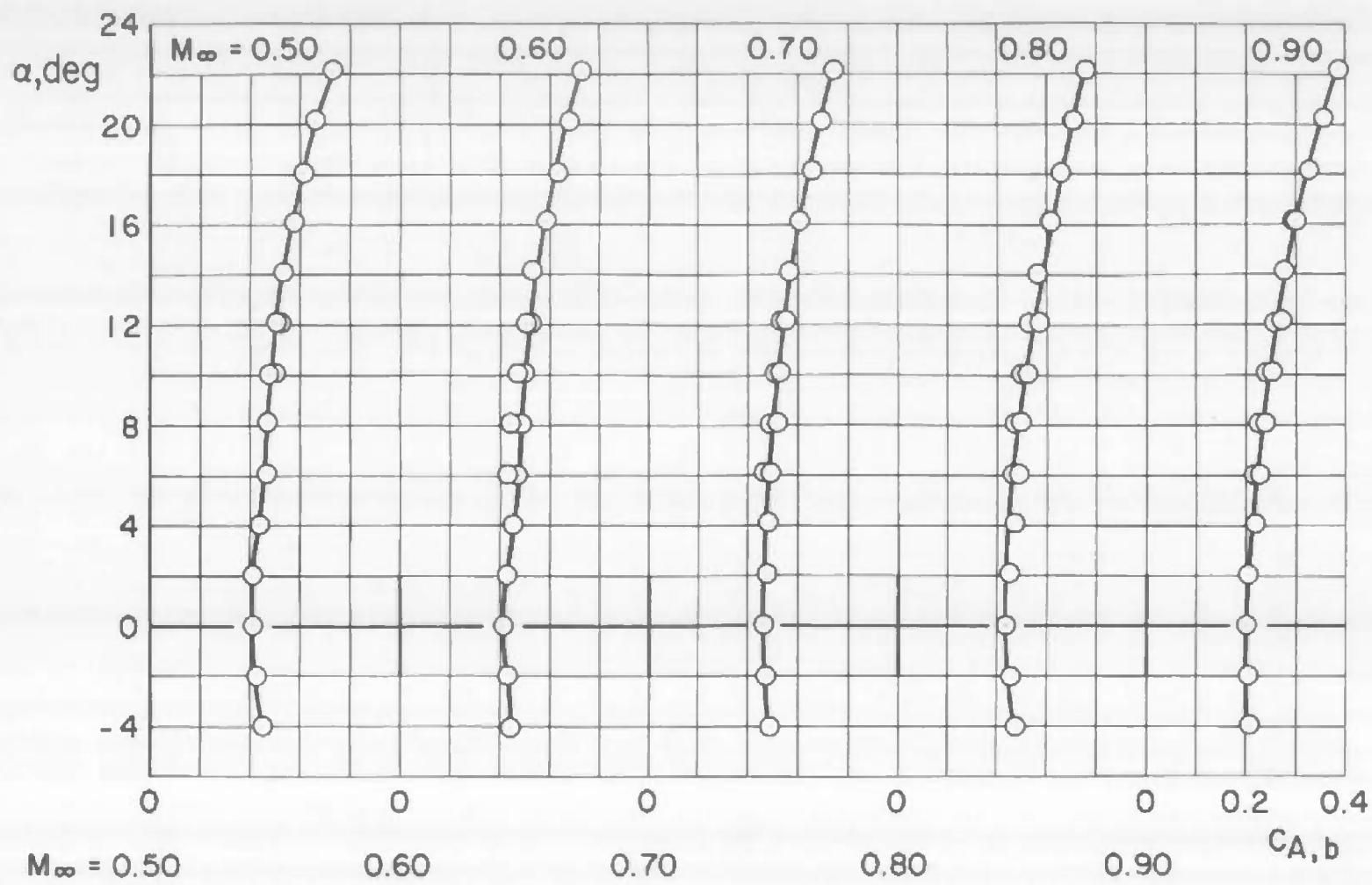
i. $C_{A, b}, M_\infty = 0.50$ to 0.90

Fig. 9 Continued
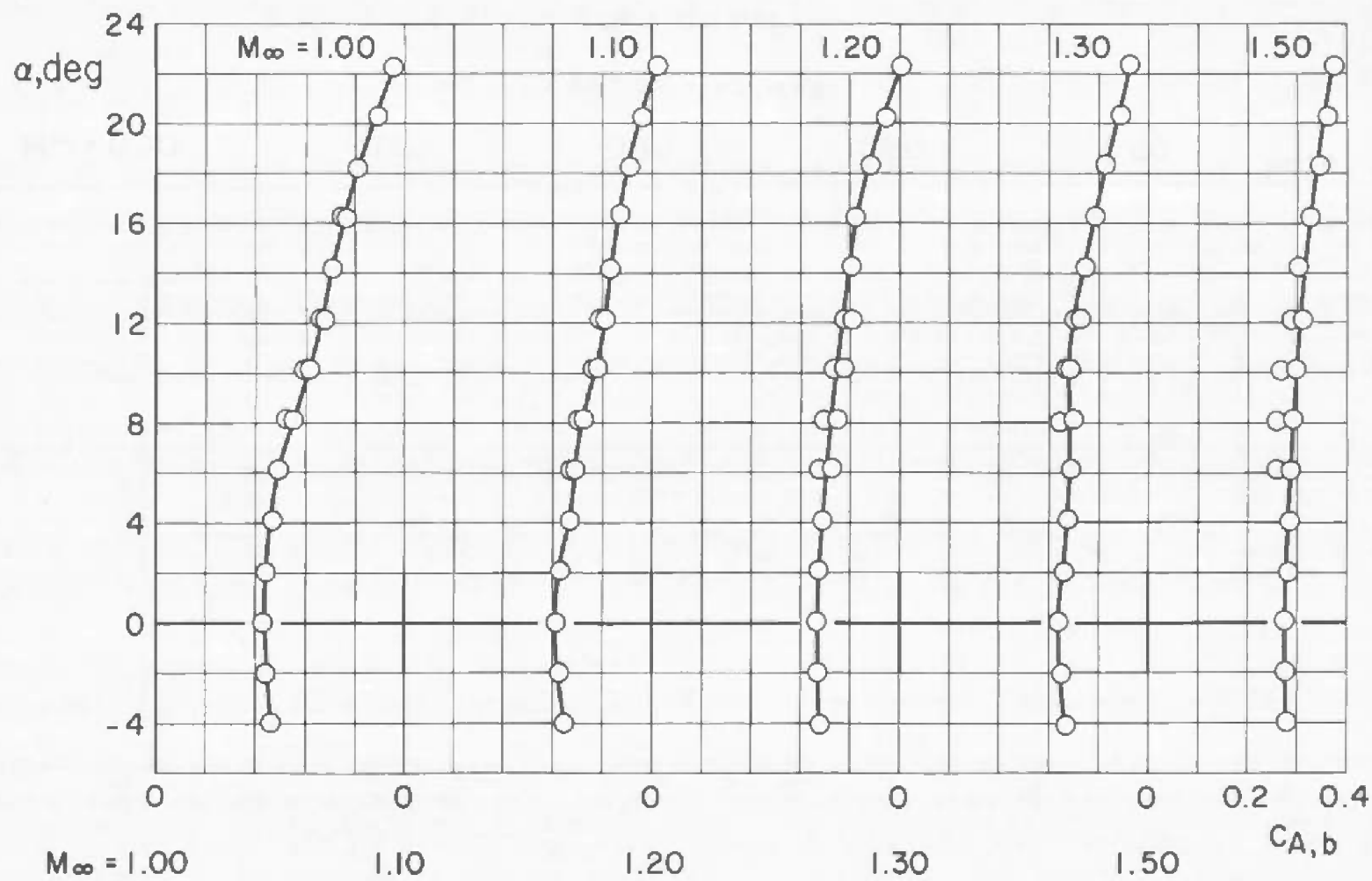
i. $C_{A, b}$, $M_\infty = 1.00$ to 1.50

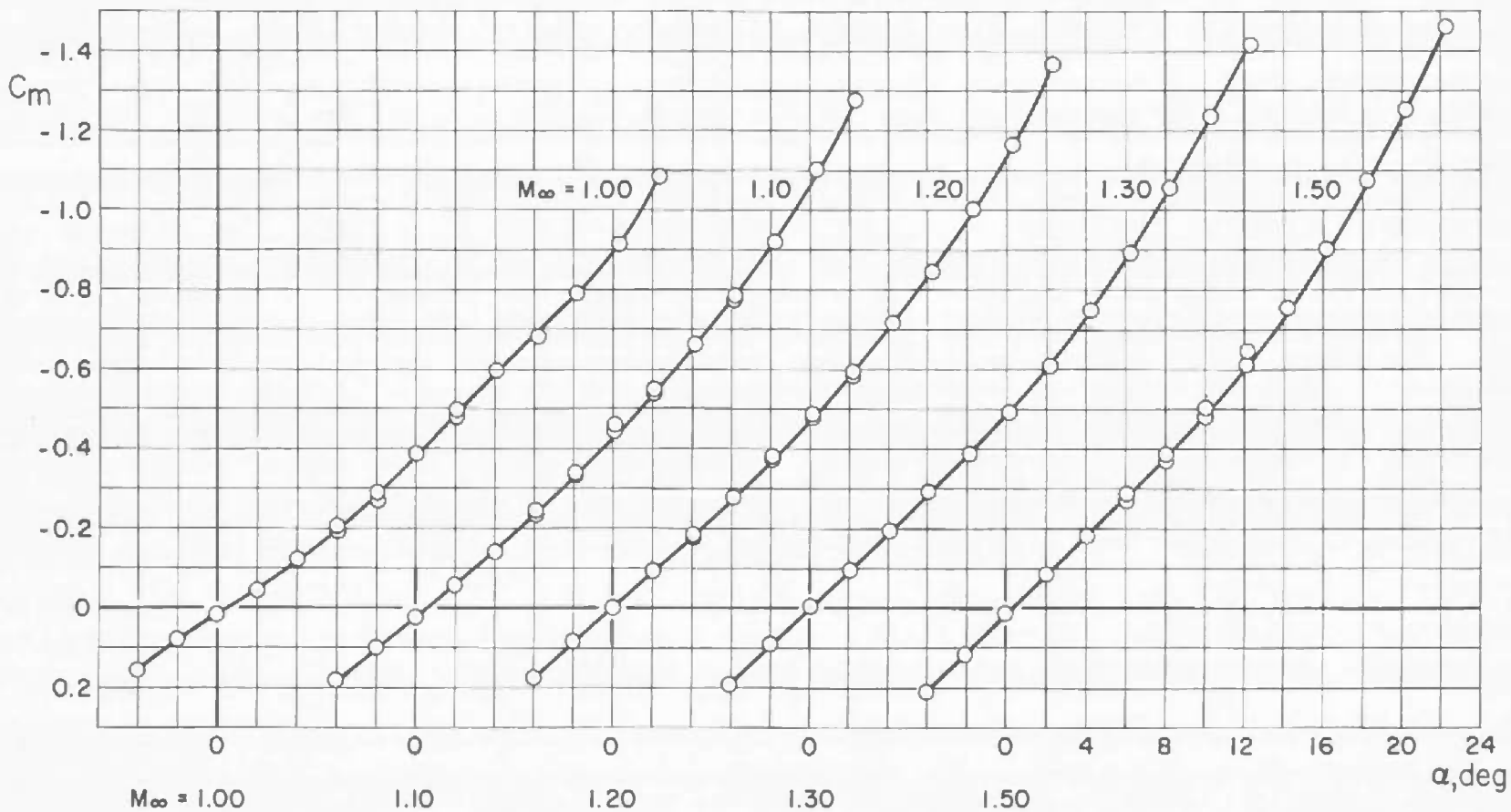Fig. 9 Concluded
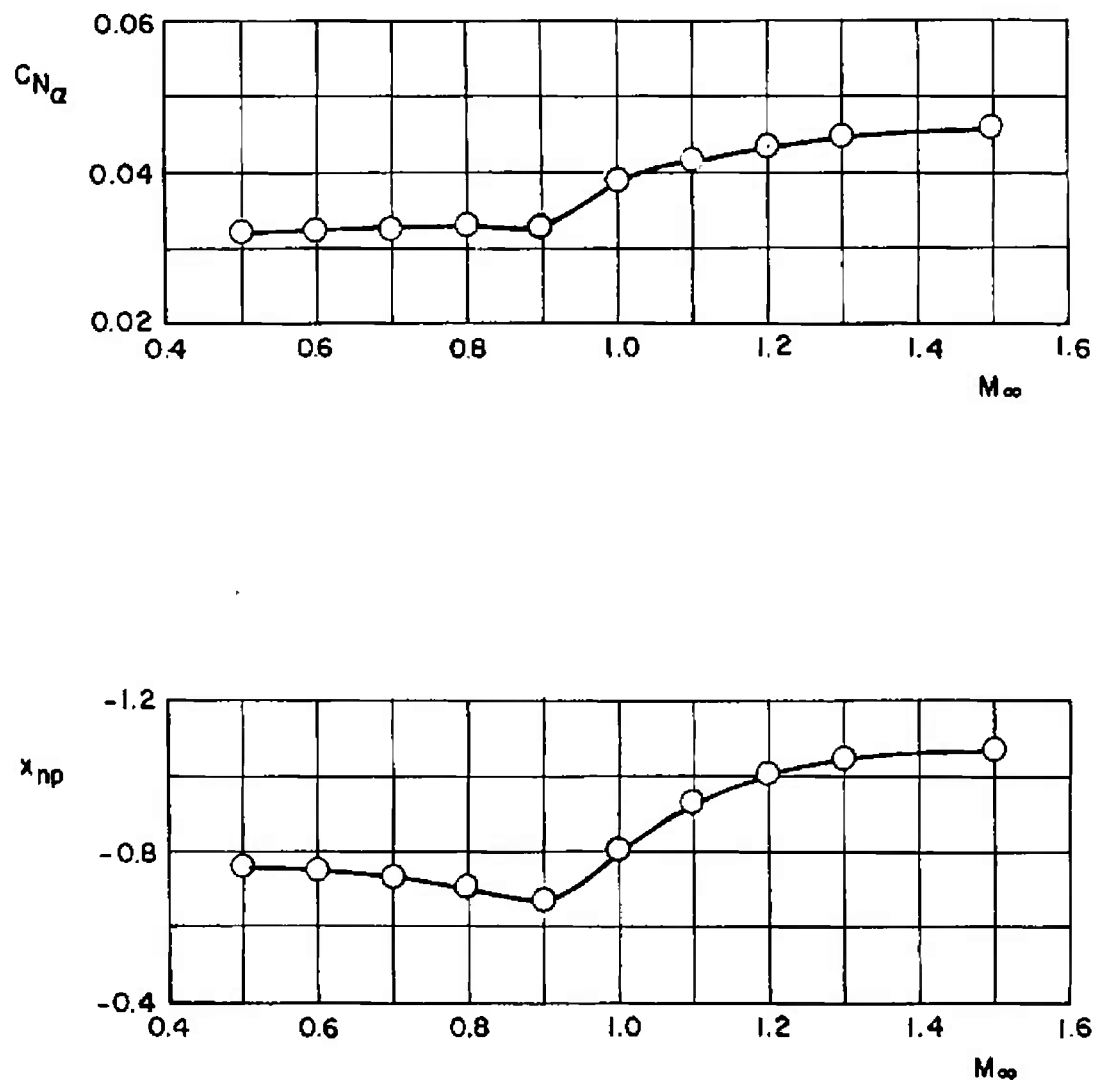
Fig. 10 Effect of Mach Number Variation on C_{N_α} and x_{np}
for the Static Stability Model, $\alpha = 0$ deg
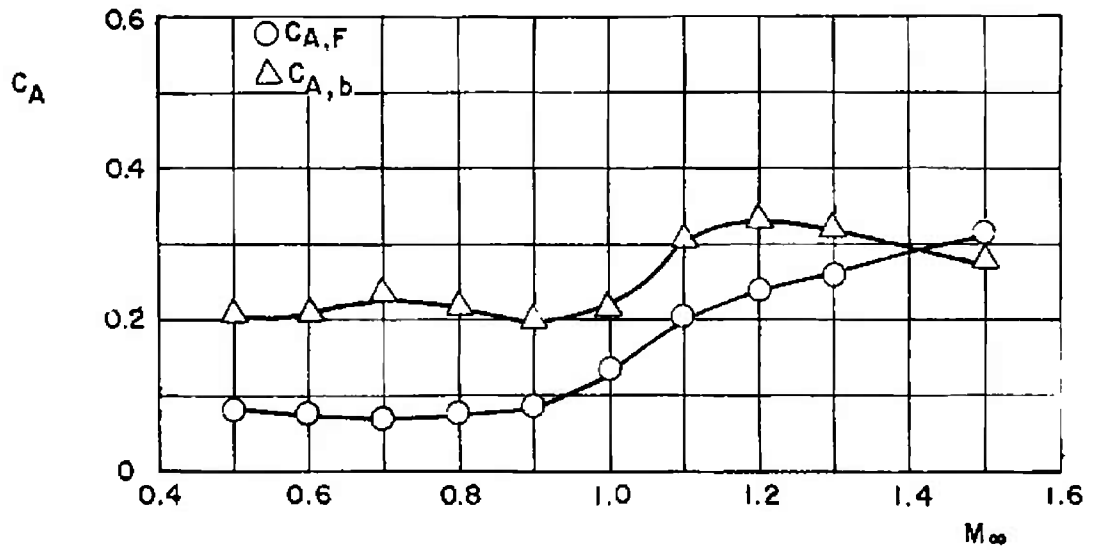
Fig. 11 Effect of Mach Number Variation on the $C_{A,F}$ and $C_{A,b}$ for the Static Stability Model, $\alpha = 0$ deg

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13 ABSTRACT

Drag data were obtained at Mach numbers 0.5, 0.8, and 1.2 for the Goodyear Aerospace Corporation ballute decelerator in the wake of the payload of the Air Launch Air Recovery Rocket (ALARR). Two model sizes of the ALARR payload were tested at angles of attack of 0 and 20 deg placed at 2, 3, 4, 5, and 6 payload diameters forward of the decelerator. The decelerator remained at zero angle of attack. The wake influence of the larger payload reduced the drag of the decelerator, both at 0- and 20-deg angles of attack. In addition, static stability characteristics were obtained on the ALARR payload for a Mach number range from 0.5 to 1.5 and an angle-of-attack range from -4 to +22 deg. To maintain static stability the center of gravity cannot move more than 29 percent of the model length aft of the nose.

DD FORM 1473
1 JAN 64

KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
ALARR						
scientific rockets						
static stability characteristics						
ballute decelerators						
drag data						
transonic flow						
wind tunnel tests						

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